J. Anat. (1991), **175**, pp. 203–212
With 5 figures
Printed in Great Britain

The ulnar collateral ligament of the human elbow joint. Anatomy, function and biomechanics

FRANZ K. FUSS

Institute of Anatomy (*1st Department*), *University of Vienna, Währinger-Str.* 13, *A*-1090 *Vienna, Austria*

(*Accepted* 18 *October* 1990)

INTRODUCTION

The ulnar collateral ligament has been reported to consist of three parts (Williams & Warwick, 1980). Its anterior part is attached to the coronoid process. The insertion of its posterior part, which has sometimes been called 'Bardinet's ligament', is medial to the olecranon. Between these two parts intermediate fibres are interposed. The third portion, also known as 'Cooper's ligament' is a transverse band spanning the notch between the coronoid process and the olecranon. To quote Morrey, "the transverse ligament seems to contribute little or nothing to elbow stability because its fibres span the medial border of the semilunar notch from the coronoid to the olecranon. Although occasionally these fibres may be rather well demonstrated, frequently the so-called transverse ligament... can hardly be defined" (Morrey, 1985).

In terms of the simplest functional concept, the anterior portion of the ligament is taut in extension and the posterior part in flexion (Gegenbaur, 1888). In Benninghoff (1985) the anterior part is thought to be taut in extension with some fibres taut in all joint positions. In the descriptions by Braus (1921) and by Schwab, Bennett, Woods & Tullos (1980) the anterior part is taut both in extension and in flexion; in that by Morrey & An (1985) it is taut from 60° to maximal flexion, and in that by Santos Gutierrez (1964) it is taut in maximal extension. While postulating an undifferentiated action for the anterior band as a whole, Santos Gutierrez nevertheless distinguished various fibre bundles by their origins; he described fibres that were taut in extension, as they arose anterior to the axis and took a straight course when taut, and anterior band fibres which also arose from the anterior surface of the epicondyle but posterior to the axis, so that they might be expected to be taut in maximal flexion; as the latter fibres were diverted around the inferior border of the medial epicondyle during maximal extension, the resultant hypomochlion (fulcrum) effect also made them taut in maximal extension. While there is general agreement that the posterior portion of the ulnar collateral ligament is taut in maximal flexion, Santos Gutierrez (1964) claimed that, like the anterior portion, it was taut in maximal extension, due to increasing distance between its attachment sites from the mid-position of the joint to maximal extension.

While this study addresses the anatomy of the ulnar collateral ligament and the biomechanical implications of its functions, the main emphasis has been on the multiplicity of the constituent fibre bundles and their functions, which allow for further differentiation, as shown elsewhere for the cruciate ligaments of the knee joint (Fuss, 1989).

MATERIALS AND METHODS

The material consisted of five fixed and fifteen fresh elbow joints. In all of them the ulnar collateral ligament was exposed and the adjacent capsular components were removed. In the five fixed specimens, Cooper's band, including the few intermediate fibres attached to it, was dissected away and the periosteum around the sites of ligamentous attachment was scraped off. Once scraped clean, the bone was varnished black. Using forceps, the collateral ligament was then split into smaller bundles and each of these artificial bundles was cut at both of its attachments to reconstruct the topography of the fibres. The sites of attachment surrounded by black-stained bone were varnished white in order to get a more precise idea of their size and extent.

In order to define the functions of the fibre bundles making up the ulnar collateral ligament and to examine the ligament for the presence of any consistently taut fibre bundles, the following procedures were used. The humerus of five fresh specimens was first mounted on a clamping device so that the axis of the humero-ulnar joint was perpendicular to the support. With the ulna in five different positions from maximal extension to maximal flexion, lateral films were obtained on a photographic reproduction device to establish whether or not the axis of ulnar movements consistently passed through the origin of the ligament.

Using the method detailed below, three of the fresh specimens were then examined. When the usefulness of the method had been established, the remaining seven fresh specimens were also analysed. The humerus was mounted as described above. Then a single selected fibre bundle was examined and, using a vernier calliper, that position was identified in which the distance between the attachments was greatest, in other words, in which the bundle was taut. If the bundle was taut in only one position, no matter whether extreme or intermediate, it was cut at its attachments. The points of attachment were colour-coded. The position in which the bundle was taut was recorded and photographed for later reconstruction. Finally, a valgus stress was applied and stability was tested. This procedure was done for all of the thin, selected bundles, one by one, without paying attention to any specific sequence. In fact, the sequence was varied from one specimen to the next. The only set rule, dictated by the underlying morphology, was that superficial fibre bundles had to be examined first. This procedure helped to establish whether any given bundle was taut in all joint positions, i.e. if the distance between its points of attachment remained unchanged. In this case it was not cut like all other bundles. Inadvertent injury or removal of this bundle manifested itself in valgus instability. As in the cruciate ligaments of the knee joint, which have been described elsewhere (Fuss, 1989), the term 'guiding bundle' is proposed for a consistently taut fibre bundle. As the method used to identify it has no equivalent in the literature, the technique has been named 'guiding bundle isolation'.

Slight hyperflexion and hyperextension were simulated by computer means. This method was used to establish which fibre bundles are most, or least, elongated when restricting movement.

RESULTS

Anatomy

The origin of the ulnar collateral ligament extends from the inferior surface to the anterior and posterior surfaces of the medial epicondyle (Fig. 1). Within it, the areas occupied by the anterior and the posterior part of the ligament can only be separated by dissection. The ulnar insertions of the two parts, by contrast, are neatly separated

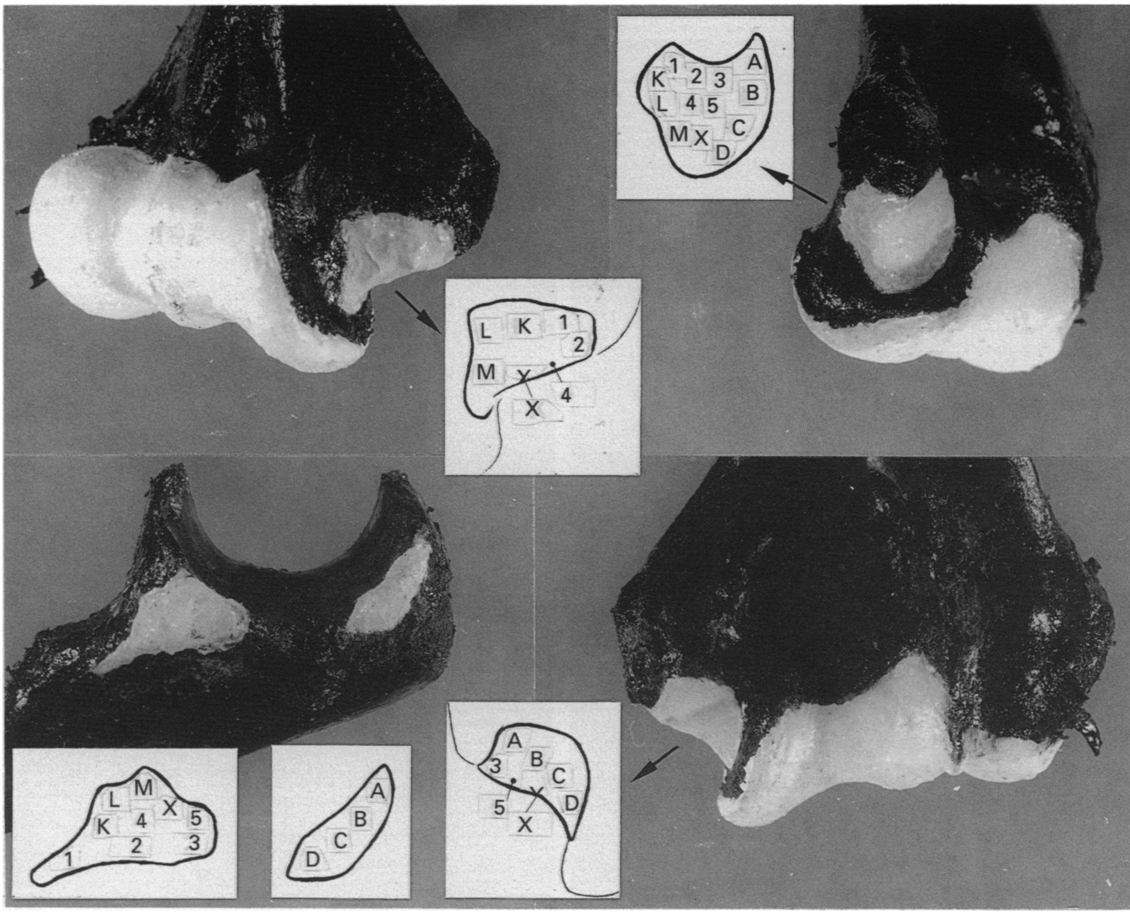

Fig. 1. Attachments of the ulnar collateral ligament (stained white, as is the articular surface on the humerus). Origin is from anterior, medial (upper row) and posterior (lower row) aspects. Anterior and posterior ulnar insertions from the medial aspects (lower row). Identically lettered or numbered sites are connected by fibre bundles.

by the notch on the ulna, which is spanned by the more or less well-developed transverse band (Cooper's ligament) used by some few and thin intermediate fibres for their insertion. When the two parts of the ulnar collateral ligament are dissected and divided into several fibre bundles, they can be seen to be quite different from one another: in the anterior part the fibres are much more closely packed than in the posterior part, so that separation of the anterior fibre bundles is much more difficult than that of those in the posterior part. Figure 1 shows the topography of the fibres in the two parts. Sites marked by the same letters or numbers are connected by fibre bundles. One of the specimens examined showed an interesting variation: the bundle marked '1' in Figure 1 was found to be a round band about twice as long as other equivalent bundles and inserted far distal on the ulna (Fig. 3).

Function

The method used to establish whether the axis passes through the humeral ligamentous attachment proved to be successful and suggested the existence of a constantly taut fibre bundle. The method of measuring the distance between the fibre

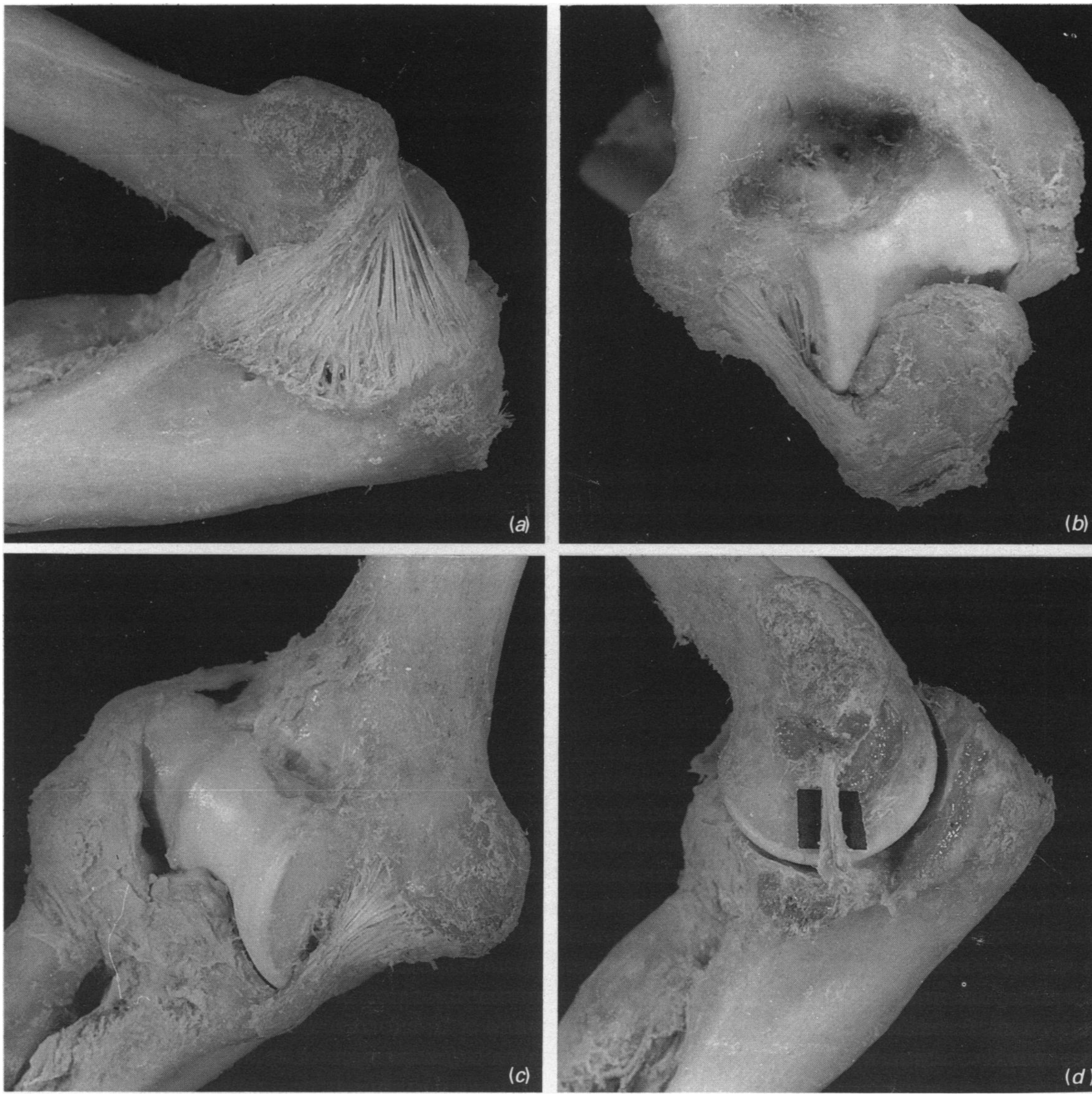

Fig. 2 (*a–d*). Maximal flexion, viewed from medial (*a*) and posterior (*b*) aspects: posterior portion taut. Maximal extension, viewed from anterior aspect (*c*): most anterior fibres taut. (*d*) Guiding bundle (with black background).

bundle attachments resulted in three functionally distinct types of fibre bundles: (i) bundles taut in extreme joint position, (ii) bundles taut in intermediate joint positions, and (iii) a bundle that was taut throughout the full range of joint motion. While the posterior part of the ligament (A–D in Fig. 1) with all its fibres is taut only if the joint is fully flexed (Figs. 2*a*, *b*, 4), the anterior part contains all three functional fibre components (Fig. 4): fibres taut in full extension (K, L, M in Fig. 1) arise from the anterior surface of the medial epicondyle (Fig. 2*c*); fibres taut in any one position between middle position and full flexion (1–5 in Fig. 1) arise from below the tip of the epicondyle (Fig. 3); and fibres grouped into a bundle (X in Fig. 1), which is always taut, arise from the inferior edge of the epicondyle. This bundle serves to guide joint

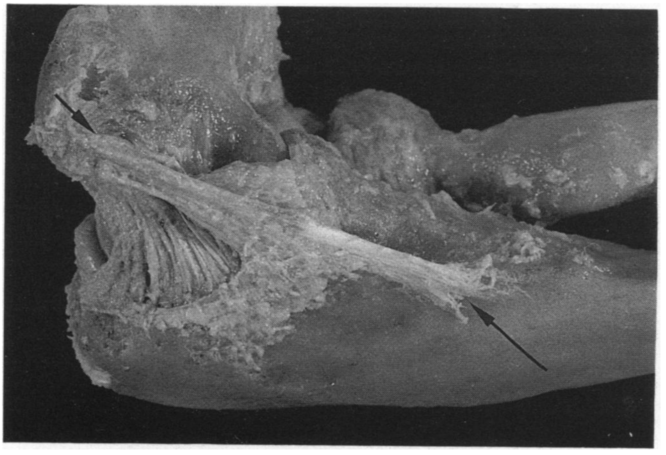

Fig. 3. 90° flexion. The bundle marked by arrows is taut and unusually long in the specimen shown (variant).

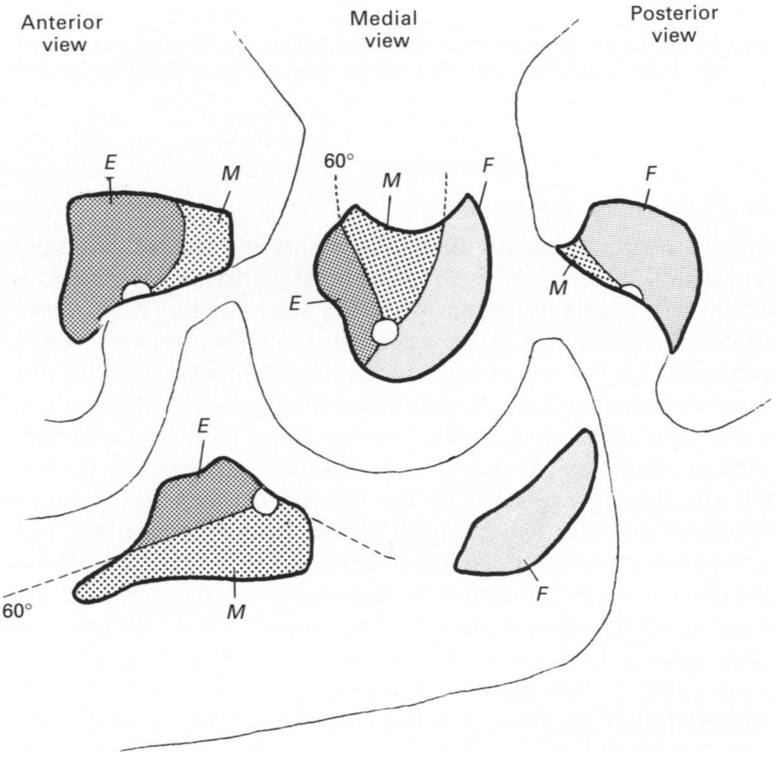

Fig. 4. Functional distribution of attachment zones (cf. Fig. 1). Attachment zones of (posterior part) bundles taut in *flexion* (*F*) *sparsely hatched*; attachment zones of bundles taut in *intermediate joint positions* (*M*) *moderately hatched*; attachment zones of bundles taut in *extension* (*E*) *boldly hatched*. Attachment zones of *guiding bundle* shown as *white* circular area.

movements and should, therefore, be called the guiding bundle (Fig. 2*d*, 4). It is of interest to note that in intermediate positions between full extension and middle position this guiding bundle is the only part of the ligament to be taut.

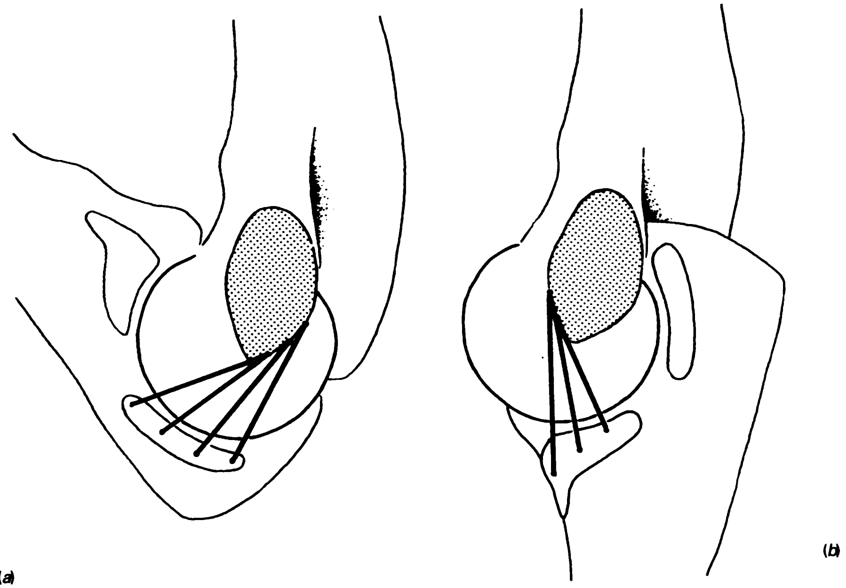

Fig. 5 (*a–b*). Flexion (*a*) and extension (*b*) in the humero-ulnar joint. Hatched area outlines sagittally cut medial epicondyle. Taut fibres are not diverted. Most posterior bundle in (*b*) is the guiding bundle.

Biomechanical properties

Limitation of elbow joint movements

Computer simulation based on fibre attachments and lengths with the joint slightly hyperextended and hyperflexed showed the most posterior fibres (Fig. 5*a*) to be the most powerful constraints of flexion, while the most anterior fibres were found to be the most powerful constraints of extension. In this context, this is taken to mean that fibres showing the lárgest percentage elongation, compared to other fibres, generate the greatest counteracting force. The external force introduced into the joint and the counteracting force generated by the limiting fibres push the articulating surfaces against one another. As a result, the articular cartilage is compressed. Joint movements are, therefore, limited by the balance between the 'counterpull' of the limiting ligament and the 'counterpush' of the articular cartilage rather than by locking of the bony processes at the upper extremity of the ulna into the corresponding fossae. The latter mechanism cannot be responsible for limiting joint movements, as the fossae are not designed as abutments. They merely mirror the bony projections on the ulna (see below). Locking, in fact, does not occur as long as the constraining ligaments are intact. If they are torn, the locking site will act as the fulcrum for the resultant dehiscence of the joint, which eventually will lead to dislocation.

The problem of joint guidance

This account so far has implied that the guiding bundle is consistently taut. It is, however, important to note that the tension of its component fibres continually changes during movements so that not all of the fibres will be taut at all times. This would only apply if the joint had an invariable axis, i.e. if it truly were a hinge in the classical engineering definition, and if it were made of non-compressible or non-stretchable material. The existence of an 'ideal guiding bundle', which would have to be unidimensional or arise from a single point, is precluded by the following factors:

(i) The joint does not comply precisely with the geometry of the perfect circle (see Discussion). Any deviation from the ideal circular geometry, of necessity, implies a shift in the position of the axis, even though this shift is confined to an extremely small area. (ii) The articular cartilage deforms under stress, i.e. the 'pull' and 'push' in the joint. (iii) The humero-ulnar joint has a screw axis. That this does not cause measurable variations in the length of the guiding bundle is due to the fact that the bundle is roughly perpendicular to the screw axis.

Interactions between bony and ligamentous structures to ensure optimal joint freedom

The extensive freedom of motion in the humero-ulnar joint requires a balance between the following factors: the height of the coronoid and the olecranon, which determines the extent to which the jaws of the proximal ulnar end engage the trochlea, the depth of the fossae on the distal end of the humerus, the site of the ligamentous attachments and the length of the ligamentous fibres. Apparently, all of these factors are related to the position of the anterior inferior and the posterior inferior aspects of the medial epicondyle. These enclose an angle, the size of which just prevents the limiting fibres from being diverted along the inferior border of the epicondyle (Fig. 5).

DISCUSSION

The question that needs to be answered before discussing ligament function is about the nature and component parts of the collateral ligament complex. No doubt, only the humero-ulnar fibres are relevant in this context, while those making up Cooper's ligament are not, although some authors, including Braus (1921) and Platzer (1979), thought them to constitute a third component ('pars transversa' or 'transverse segment') of the ulnar collateral ligament. In actual fact, Cooper's ligament is limited to the ulna and does not span the joint, so that it cannot form part of the true ulnar collateral ligament. It should rather be regarded as a separate entity which would, no doubt, have deserved a name of its own, e.g. 'olecranocoronoid ligament of Cooper'. This does not, however, necessarily imply that this band is topographically unrelated to the ulnar collateral ligament. The ulnar collateral ligament itself consists of two parts. This is reflected by its pattern of attachment. As it has two bony attachments at one end, and only one at the other end, it does not make sense to interpret any one of its component bands as a separate ligament. This has, in fact, been done for the posterior limb which was named 'Bardinet's ligament', although it would, at best, have deserved to be called 'pars'. If two separate attachments were identifiable proximally, two separate ligaments would be present. In fact, Morrey & An (1985) thought that the two parts have two separate origins, both small and discrete and posterior to the joint axis, as shown in their Figure 3. Taking this pattern as a basis for explaining function, they described the posterior part as being taut in full flexion and the anterior part as being taut between 60° flexion and full flexion. While showing very little change, the distance between the origin and insertion in their Figure 4 reaches a maximum at 80°. This compares with maxima at 60°, 90° and 120° flexion shown in Figure 3–19A of Morrey's book (1985). For the few fibres which arise from the areas defined by Morrey & An the tension pattern described by them agrees well with our own observations. The functional anatomy described by Morrey & An would, however, imply that the collateral ligament does not contain any fibres that are taut in extension or rather that the joint does not have a medial stabiliser for the range between full extension and 60° flexion. This is, however, contradicted by Morrey's statement (1985) that "valgus stress in extension is equally divided between the medial collateral ligament, the capsule and the joint surface". Even if one appreciates that Morrey & An were the first to analyse the relationship between the humeral attachment and the joint axis, as they themselves stress ("This relationship has not been previously demonstrated"), their description of the humeral attachment does not reflect the true situation so that the functional concept based on it is inappropriate. This may be attributable to the method used by Morrey & An: as they defined the origins of both parts with vascular clips, they were unable to identify the origins of the fibres deep to the superficial fibre bundles.

Our own observations are in full agreement with the succinct description of the function of the ulnar collateral ligament given in Benninghoff (1985): the anterior band is primarily taut in extension, but it also contains fibres which are never entirely relaxed. The posterior band is taut in flexion. However, in Benninghoff's book the ligament is thought to arise along a humeral 'line' of origin intersected by the transverse joint axis. Our observations also agree with those of Schwab *et al.* (1980) particularly with their concept that sectioning of the posterior portion did not result in any significant alteration of elbow stability, while sectioning of the anterior portion caused marked valgus instability, suggesting that this portion is the major medial ligamentous joint stabiliser. In the account of Schwab *et al.* there is, however, no reference to anterior limb fibres that are taut in intermediate joint positions.

The data reported by Santos Gutierrez (1964) merit the following comments: it is true that the anterior portion limits extension. The inferior border of the epicondyle, however, does not act as a hypomochlion (fulcrum) diverting those anterior part fibres which arise posterior to the axis so that they become taut in extension. These fibres, rather, are taut in intermediate joint positions. They are, in fact, slightly curved at the level of the epicondyle with the joint fully extended. This is, however, not due to a hypomochlion effect. It is, in fact, brought about by thin connecting fibres tethering these fibre bundles to adjacent ligament structures. In the description by Santos Gutierrez the posterior part limits both flexion and extension. The latter conclusion is substantiated by Santos Gutierrez's Figure 7 which clearly shows an increase in the distance between ligament attachments from the middle position to full extension. With the aid of dividers one can, however, easily see from this illustration that the distance, while increasing from the middle position to both full extension and maximal flexion, is largest in maximal flexion. Consequently, this illustration furnishes, although unintended, proof of the true function of this portion of the ligament.

Textbooks (e.g. Fick, 1911) describe the humero-ulnar joint as a classical hinge joint with special reference to its screw axis. Shiba *et al.* (1988), however, showed that the comparison with a technical hinge cannot be maintained. They found that the articular surfaces of humerus and ulna did not correspond precisely to circular geometry. This coincides with the results of Morrey & Chao (1976): the instantaneous centre of rotation moves within 2·5 mm during humero-ulnar motion. These minute deviations can nevertheless be brought into agreement with the existence of a guiding bundle.

Various mechanisms have been suggested to explain limitation of joint motion. In almost all of the more recent reports the ligaments are accorded a prime role, the only exception being that of Kapandji (1984) who, in more general terms, speaks of the joint capsule. While Santos Gutierrez (1964) thought the ligaments alone to be responsible, others postulated the existence of additional or even more important mechanisms. One of these is resistance to passive muscle elongation, which is mentioned in the reports of Sieglbauer (1930), Kapandji (1984) and Benninghoff (1985). Locking of the ulna in the fossae at the distal end of the humerus is expressly mentioned as a constraining factor by Fick (1911) and Benninghoff (1985) and has, just as expressly, been rejected by Santos Gutierrez (1964). In Benninghoff's book this statement is qualified by adding that the bony constraint is the final link in the chain of events. This can at best be based on the following concept: as the constraining ligament is taut, the only effect a continued moving force would have is to move the ulna around the ulnar insertion of the taut ligament. Depending on the direction of this hypothetical movement, i.e. on whether the elbow is extended or flexed, the olecranon or the coronoid would be pressed against the base of the corresponding fossa on the humerus. At the same time the entire large adjacent cartilaginous articular surface of the ulna would be pressed against the articulating surface on the humerus so that the resistance generated by these cartilaginous structures would prevent the bony structures from making contact with each other. This is the mechanism Santos Gutierrez (1964) obviously had in mind when he talked of a "gradual reciprocal pressure between the humeral and ulnar articular surfaces" produced by the ligaments. Consequently, the fossae at the distal end of the humerus only serve a single purpose: to make room for the coronoid and the olecranon in order to ensure extensive freedom of joint motion and provide for an optimal engagement of the trochlea by the jaws of the trochlear notch. That it cannot, at the same time, act as an abutment to check the movements of the coronoid and the olecranon is obvious.

In conclusion, it is scarcely surprising to find that the function of the ulnar collateral ligament matches that of the cruciate ligaments of the knee joint. Like the ulnar collateral ligament, the cruciates carry (i) fibres limiting extension and flexion, (ii) fibres taut in intermediate joint positions and (iii) a guiding bundle (Fuss, 1989). The differences in the mechanical nature of the knee and elbow joints do not alter the basic function of their ligaments.

SUMMARY

The posterior portion of the ulnar collateral ligament, which arises from the posterior surface of the medial epicondyle, is taut in maximal flexion. The anterior portion, which takes its origin from the anterior and inferior surfaces of the epicondyle, contains three functional fibre bundles. One of these is taut in maximal extension, another in intermediate positions between middle position and full flexion while the third bundle is always taut and serves as a guiding bundle. Movements of the elbow joint are checked by the ligaments well before the bony processes forming the jaws of the trochlear notch lock into the corresponding fossae on the humerus.

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